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Transmitted herewith for filing is the Patent Application/of:

Inventors: Kai Cieliebak and Beat Liver

For: Portfolio Theory Method of Managing Operational Risk with Respect to  
Network service-Level Agreements  
Enclosed are:

☒ 12 (twelve) Sheets of Informal Drawings.☐ An assignment of the invention to International Business Machines Corporation, Armonk, New York 10504.☐ A certified copy of a \_\_\_\_\_ application.☒ Unsigned Declaration and Power of Attorney is attached to the application.☐ Associate Power of Attorney.☐ Information Disclosure Statement with form PTO-1449 with references attached.

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Respectfully submitted,

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1 PORTFOLIO THEORY METHOD OF MANAGING OPERATIONAL  
2 RISK WITH RESPECT TO NETWORK SERVICE-LEVEL  
3 AGREEMENTS

4 CROSS REFERENCE TO RELATED APPLICATION

5 This application claims priority to co-pending U.S.  
6 provisional application no. 60/162,383 filed October 28, 1999.

7 Field of the Invention

8 This invention relates to a method of managing risk, and  
9 more particularly, to a method of managing operational risk and return  
10 with respect to network service-level agreements ("SLA"s).

11 Background of the Invention

12 In order to ensure economical network operations, providers  
13 are concerned with the following trade-off: on the one hand, better  
14 Quality of Service corresponds to higher price, thereby increasing  
15 revenue. On the other hand, if the provider guarantees higher Quality of  
16 Service and is not willing to run a higher risk, he can only accept less  
17 traffic, thereby decreasing revenue. In order to properly evaluate this  
18 trade off, the provider attempts to manage operational risk associated  
19 with non-complying network service-level agreements.

20 In the prior art, operators employ simple traffic engineering  
21 to meet the QoS as specified in the SLAs. For example, sensitivity  
22 analysis is carried out to determine the likelihood of violating SLAs.

1                   Therefore, what is needed is a systematic method to evaluate  
2 risk and return with respect to network service-level agreements that can  
3 be implemented on a computer in order to provide near real time  
4 assessments of performance, thus providing more accurate risk  
5 assessments and less uncertainty.

6                   Summary of the Invention

7                   It is therefore an object of the invention to provide a method  
8 of managing operational risk and return with respect to a portfolio of  
9 classes of service-level agreements (“SLA”s). The method executes the  
10 following steps: (1) calculating an efficient frontier that identifies  
11 efficient portfolios of SLAs using inputs such as characteristics of the  
12 production infrastructure, traffic and QoS characteristics and the price of  
13 each class of SLAs; (2) optionally, calculating a baseline efficient  
14 frontier using inputs such as market pricing and break-even (zero-profit)  
15 pricing; (3) determining the performance of the current portfolio of  
16 SLAs using a portfolio evaluator means and inputs which characterize  
17 the current portfolio; (4) evaluating performance by comparing the  
18 current portfolio and the efficient portfolios with the desired level of risk  
19 and return; and, if desired, implementing corrective action based on any  
20 desired risk and return.

21                   Brief Description of the Drawings

22                   The above brief description, as well as further objects,

1 features and advantages of the present invention will be more fully  
2 appreciated by reference to the following detailed description of the  
3 presently preferred but nonetheless illustrative embodiments in  
4 accordance with the present invention when taken in conjunction with  
5 the accompanying drawings.

6 FIG. 1 is a flow diagram of the method of the invention.

7 FIG. 2 is a schematic diagram of a computer device on  
8 which the invention operates.

9 FIG. 3 is a diagram of a network on which the invention  
10 may be implemented.

11 FIG. 4 is a detailed flow diagram of the method of the  
12 invention.

13 FIG. 5 is a schematic view showing portfolio theory applied  
14 to network operations.

15 FIG. 6 is a flow chart illustrating a Portfolio Evaluator of  
16 the invention.

17 FIG. 7 is a graph of risk vs. return showing the efficient

1 frontier.

2 FIG. 8 is a schematic diagram of an SLA.

3 FIG. 9 is a graph showing examples of extremal points.

4 FIG. 10 is a graph of a polyhedron of constant return.

5 FIG. 11 is a schematic view of an example ring network.

6 FIG. 12 is a graph of the normalized traffic distribution X.

7 FIG. 13 is a zero-profit price curve.

8 FIG. 14 is a graph of the risk and return of portfolios.

9 Detailed Description of the Invention

10 Glossary of Terms and Symbols

11  $\beta C$  financial penalty per capacity unit.

12  $C$  capacity C (of stem, network, link and so on)

13  $\mathbf{D}$  vector of Quality of Service classes, in case of delay

14  $D_i$  Quality of Service offered by class i in case of delay

15  $e(\gamma)$  return of a portfolio  $\gamma$

- 1  $\underline{L}$  vector of Quality of Service classes, in case of loss ratio
- 2  $L_i$  vector of Quality of Service classes in case of loss ratio
- 3  $p_c C$  constant term reflecting the marginal cost of providing the
- 4 network.
- 5  $P$  denotes a portfolio
- 6  $\underline{p}$  price vector
- 7  $p_c$  unit price for capacity  $C$
- 8  $p_i$  price of contract of type  $i$  (expected revenue)
- 9  $\underline{q}$  contracted Quality of Service of the contracts of the portfolio;
- 10  $\underline{q}'$  (expected) actual Quality of Service of a network
- 11  $r(\underline{y})$  risk of a portfolio  $\underline{y}$
- 12  $r_{QoS}(\underline{y})$  Quality of Service risk, i.e., risk expressed in terms of QoS units
- 13  $r_s(\underline{y})$  financial risk, i.e., risk expressed in terms of monetary units
- 14  $\mathbf{R}$  rational numbers
- 15  $\mathbf{R}_+$  rational numbers that are greater than 0
- 16  $\mathbf{R}^n$   $n$ -dimensional space, where each dimension is of  $\mathbf{R}$
- 17  $\underline{y}$  a portfolio, i.e.,  $\underline{y} = \langle y_1, \dots, y_n \rangle$
- 18  $y_i$  amount of contracts (SLAs) of type  $i$

19 Referring now to FIG. 1, which is a flow diagram of the  
20 invention, the invention provides a method 10 and a system 20 that  
21 applies the principals set forth in detail in provisional application no.  
22 60/162,383, hereby incorporated by reference. The method 10 manages  
23 operational risk and return with respect to a portfolio of classes of

1 computer resource or service-level agreements (“SLA”s) by executing  
2 the following steps. In a first step 12, the method 10 calculates an  
3 efficient frontier 110 that identifies efficient portfolios of SLAs using  
4 inputs such as characteristics of the production infrastructure 138, traffic  
5 and QoS characteristics and the price of each class of SLAs. In a second  
6 step 14, the method 10, optionally, calculating a baseline efficient  
7 frontier 110 using inputs such as market pricing and zero-profit pricing.  
8 In a third step 16, the method 10 determines the performance of the  
9 current portfolio of SLAs using a portfolio evaluator 144 and inputs that  
10 characterize the current portfolio. In a fourth step 18, the method 10  
11 evaluates performance by comparing the current portfolio and the  
12 efficient portfolios with the desired level of risk and return; and, if  
13 desired, implements corrective action based on any desired risk and  
14 return.

15 Referring now to FIG. 2, which is a schematic diagram of a  
16 typical system 20 for practicing the various embodiments of the present  
17 invention, the method 10 is encoded on a computer-readable medium  
18 and operates on a computer system 20 and/or between the computer  
19 system and a server 25 or 54 (shown in FIG. 3) on an intranet or the  
20 Internet. Such a computer system 20 typically includes a computer 22, a  
21 display device 24, an input device 26 such as a keyboard, a primary  
22 storage device 30 and a secondary storage device 32. After loading of  
23 software encoded with the method 10 of the invention or after accessing  
24 the server 25 or 54 through a browser such as Internet Explore 5.0, as the  
25 case may be, the display device 24 displays a graphical user interface



1 ("GUI") 34 for facilitating the display of text and graphics associated  
2 with the method to the user. Display devices 24 include printers and  
3 computer display screens such as a CRT, LED displays, LCDs, flat  
4 screens, screen phones, and projectors. Input devices 26 are numerous  
5 and include keyboards and pointing devices such as a mouse 27 having a  
6 left mouse button 28 and a right mouse button 29, a trackball, lightpens,  
7 thumbwheels, digitizing tablets, microphones using voice recognition  
8 software, and touch screens and pads.

9           The GUI 34 provides input fields for data input and control  
10 of the method 10, as well as an output window for statistical displays of  
11 information, which facilitates management of the network. The method  
12 10 accesses a database in primary storage 30, the database including  
13 information associated with each SLA, organized in a data structure  
14 including the class i of the SLA, the terms 126 of each SLA, such terms  
15 including the offered capacity 122, the Quality of Service guarantees 124  
16 with respect to delay, loss, and availability, a price 126, a penalty 130, a  
17 duration 132, and, optionally, relative compliance guarantee(s) 86a  
18 (shown in FIG. 8 ).

19           The computer 22 includes a CPU 36 as well as other  
20 components with which all who are skilled in the art are familiar. For a  
21 detailed discussion of these components and their interaction, see U.S.  
22 Pat. No. 5,787,254, the content of which is incorporated by reference.  
23 The secondary storage 32 supports the method 10, preferably  
24 HTTP-compliant, as well as a number of Internet access tools. The  
25 CPU 36 fetches computer instructions from primary storage 30 through

1 an interface 40 such as an input/output subsystem connected to a bus 42.  
2 The computer 22 can be, but is not limited to, an "IBM APTIVA"  
3 computer, a product of International Business Machines Corporation of  
4 Armonk, New York, or any computer compatible with the IBM PC  
5 computer systems based on the X86 or Pentium(TM) series processor of  
6 Intel Corporation or compatible processors, or any other suitable  
7 computer. The CPU 36 utilizes an operating system that, depending on  
8 the hardware used, may be DOS, "WINDOWS 3.X", "WINDOWS  
9 XXXX", "NT", "OS/X", "AIX", "LINUX", or any other suitable  
10 operating system. The CPU 36 executes these fetched computer  
11 instructions. Executing these instructions enables the CPU 36 to retrieve  
12 data or write data to the primary storage 30, display information, such as  
13 the statistical displays of the method 10, on one or more display devices  
14 24, receive command signals from one or more input devices 26, or  
15 transfer data to secondary storage 32 or even other computer systems  
16 which collectively form a computer network 25 (shown in FIG. 3).  
17 Those skilled in the art understand that primary storage 30 and  
18 secondary storage 32 can include any type of computer storage including  
19 RAM, ROM, application specific integrated circuits ("ASIC") and  
20 storage devices that include magnetic and optical storage media such as  
21 a CD-ROM.

22 Where the method 10 operates on a stand-alone computer  
23 22, the primary storage 30 stores a number of items including the  
24 method 10 and a runtime environment 46. The runtime environment 46  
25 typically is an operating system that manages computer resources, such

1 as memory, disk or processor time, required for the method of the  
2 invention to run. The runtime environment 46 may also be a message  
3 passing system, a microkernel, dynamic loadable linkable module(s), or  
4 any other system that manages computer resources.

5 Now referring to FIG. 4, in which a more detailed flow  
6 diagram of the method is shown, the method 10 includes the following  
7 steps. In a first step 60, the method gathers inputs from the provider  
8 including characteristics of the production infrastructure, the QoS  
9 characteristics and price of each possible and reasonable class of SLA.  
10 In a second step 62, the method 10 calculates an efficient frontier 110  
11 (shown in FIG. 7 ) that identifies efficient portfolios of SLAs.  
12 Optionally, the method 10 substitutes the actual pricing of SLAs with  
13 baseline pricing such as market pricing or break-even pricing, in order  
14 for the operator to obtain insights regarding the effects of price changes  
15 on his risk and return, with respect to the market. In a third step 64,  
16 which may run concurrently with the first and second steps 60 and 62,  
17 the method 10 gathers inputs characterizing the current portfolio of  
18 SLAs and the desired risk and return. In a fourth step 66, which may run  
19 concurrently with the first and second steps 60 and 62, the method 10  
20 computes the risk and return of the current portfolio using a portfolio  
21 evaluator 144 (shown in FIG. 6). In a fifth step 70, the method 10  
22 calculates the difference between the optimal portfolio identified by the  
23 efficient frontier 110 and the current portfolio. In a sixth step 72, the  
24 difference is evaluated. If actual risk and return matches the desired

1 levels, then an acceptable portfolio 74 has been attained and the method  
2 waits a period of time  $\Delta T$  (depicted in the figure by box 76), before  
3 restarting the method. Otherwise, in a seventh step 80, if actual risk is  
4 higher than desired risk or if actual return is lower than desired return,  
5 the method 10 takes corrective action. Corrective action can include  
6 adjusting marketing strategy 82, changing the degree of multiplexing,  
7 84, defining relative compliance guarantees and running packets through  
8 a service discipline which allows transmission on the basis of priority (as  
9 defined by the guarantees specified in the SLAs), 86, changing prices ,  
10 90, trading different classes of SLAs, 92, and/or reducing the costs of the  
11 production infrastructure 94. In a seventh step 96, after an adjustment  
12 due to the selected corrective action is made to the production  
13 infrastructure, the method 10 takes new inputs, and, with the exception  
14 of the corrective action of trading SLAs, 92, the method is re-executed,  
15 by calculating a new efficient frontier 110 which is compared with actual  
16 performance, calculated by the portfolio evaluator 144, given the new  
17 parameters.

## 18 Portfolio Theory and Service-Level Agreements

19 In calculating the efficient frontier 110, the method 10  
20 applies the principles of classical Portfolio theory — to be precise, the  
21 pre-CAPM (Capital Asset Pricing Model) version of portfolio theory,  
22 which was initially developed by H. Markowitz, W. Sharp and others for  
23 portfolios of classes of financial assets (shares, bonds, etc.), to provide a

1 framework in which to describe this trade-off between risk and return for  
2 portfolios of classes of SLAs. In the classical application of portfolio  
3 theory, it is assumed that there are finitely many assets  $i$ .

4           Each SLA in the portfolio specifies a peak rate (e.g., bits per  
5 second) and a Quality of Service guarantee (e.g., loss rate). Associated  
6 with each portfolio is its return (relative profit) and its risk of violating  
7 any of the SLAs. This risk will be referred to as non-compliance risk (the  
8 risk that any of the Quality of Service guarantees of the sold SLAs is  
9 violated). In contrast to return, risk generally cannot be quantified in  
10 monetary terms directly. Quantifying risk in monetary terms requires two  
11 steps:

- 12       1. Risk is measured in quantities specific to the asset.
- 13       2. The measured risk levels have to be valued in terms of the  
14       contract value (e.g., money-back guarantee) specified in the contracts.

15           In order to separate these two steps and apply different  
16 valuation methods, risk and return are treated as independent parameters  
17 associated with portfolios.

18           Assuming that the set of attainable portfolios is all  
19 nonnegative real numbers  $\mathbf{R}_+$  up to the number  $n$  of available assets  
20 (which is finite), each portfolio may be associated with two quantities:  
21 the (expected) return and the risk. A portfolio is called efficient if it  
22 maximizes return at a given risk, or equivalently, minimizes risk at a

1 given return. The efficient frontier 110 is the image in the risk-return  
2 space of the set of efficient portfolios.

3 Treating the contracts, e.g., SLAs, of a service provider as a  
4 portfolio makes it possible to develop decision-support tools for  
5 determining the Quality of Service classes to be offered and for  
6 managing the noncompliance risk — an operational risk resulting from  
7 multiplexing (and other behaviors of a production infrastructure in  
8 operation). One such management strategy, corrective action 86, defines  
9 a new contractual parameter called relative compliance guarantees,  
10 which will be discussed in more detail later, along with a discussion of  
11 the trading of risks.

12 Referring now to FIG. 5, a network service provider sells  
13 connectivity over a network 100. The provider offers  $n$  classes of  
14 service level agreements  $SLA_1 . . . SLA_n$ . Each SLA specifies a  
15 connection, contract duration, traffic descriptors (peak rate, average rate,  
16 burst size, etc.) and Quality of Service guarantees (loss rate, delay, jitter,  
17 etc.). An SLA is normalized to a peak rate (or average rate) of 1 bit/s.  
18 Then the provider's portfolio of SLAs is given by a vector  $\underline{y} \in \mathbf{R}_+^n$   
19 whose component  $y_i$  is the number of contracts of class  $i$ .

20 Associated with each portfolio are two quantities: the  
21 (expected) return  $e(\underline{y})$  and the risk  $r(\underline{y})$ . The return (or profit) of a  
22 portfolio  $\underline{y}$  equals  $e(\underline{y}) = \sum p_i y_i - p_c C$  where  $p_i$ ,  $C$  and  $p_c$  denote the unit  
23 price of class  $i$ , the capacity of the network and the unit price of network  
24 capacity respectively. Note that  $p_c C$  is a constant term reflecting the

1 marginal cost of providing the network. The unit price  $p_c$  depends on  $C$   
2 as networks 100 exhibit economies of scale in general. In the case of a  
3 single link,  $C$  is the link capacity.

4 A portfolio  $\underline{y}$  entails a risk of noncompliance  $r(\underline{y})$  for the  
5 provider that depends on the traffic statistics (i.e., the traffic that is  
6 actually sent by consumers under their SLAs within the specified traffic  
7 descriptor), as well as on the network topology and capacities. There are  
8 different risk measures conceivable (as discussed below).

9 In order to help structure his portfolio  $\underline{y}$  of SLAs, the  
10 provider must consider as inputs such factors as traffic statistics 102,  
11 market information 104, and the structure and behavior of the network  
12 100. Then, by evaluating risk and return 106, he may determine the  
13 efficient frontier 110 (discussed in detail in connection with FIG. 7).

14 The set of feasible portfolios 112 (shown in FIG. 7) and the  
15 prices  $p_i$  will be determined by the market demand. Once a network  
16 service provider has determined the appropriate risk measure, which may  
17 be any risk measure, and has derived a way to compute it, he can think  
18 about his operations in the terms of portfolio theory. Doing so enables  
19 the provider to (1) decide how many and which types of SLAs to offer  
20 (described above); (2) evaluate the efficiency of the current portfolio; (3)  
21 compute the efficient frontier 110; (4) quantify risk and return 106 of the  
22 current portfolio; (5) derive strategies to move towards a more efficient  
23 portfolio, and (6) determine base-line portfolios for (cost-based)  
24 zero-profit prices.

Evaluate the efficiency of the current portfolio .

In order to obtain the performance characteristics of the existing production infrastructure 138, for comparison with the efficient portfolio 110 (i.e., the fourth step 18 of method 10, shown in FIG. 1), a Portfolio Evaluator 144 is provided. In addition to portfolio details and the production infrastructure (characterized by the vector  $\underline{l}$ , which is fixed here and hence not further discussed), the Portfolio Evaluator 144, shown in FIG. 6, takes a Boolean variable “ $S$ ”, as input to select between risk measure 136a, “ $r_s(\underline{y})$ ”, and risk measure 136b, “ $r_{QoS}(\underline{y})$ ” (i.e., the provider decides whether he wishes to evaluate the risk of a penalty or the risk of violating a Quality of Service requirement) . The Portfolio Evaluator 144 carries out the following steps:

- (1) A Performance Evaluator 146 is invoked to determine the (expected) actual Quality of Service 150, “ $q$ ”. The Performance Evaluator 146 is a formula (if an analytical performance model exists) or a simulator. Further, the actual details of the infrastructure 138 may be used for determining performance.
- (2) The portfolio risk 136, “ $r(\underline{y})$ ”, is computed based on actual Quality of Service 150,  $q$ ’, and the contracted Quality of Service 152,  $q$ , of the contracts of the portfolio using a particular *risk measure* 136a or 136b.
- (3) The return 134, “ $e(\underline{y})$ ”, is computed according to the formula 154,



1  $\Phi y_i - p_c C$ , for capacity 140, “ $C$ ”, and capacity unit price 142,  
2 “ $p_c$ ”, where capacity 140 is an input in both the Performance  
3 Evaluator 146 and is characteristic of the production infrastructure  
4 138.

5 Risk measures 136 include the *risk of noncompliance* (i.e.,  
6 the risk of not being able to satisfy all the Quality of Service guarantees  
7 of the sold contracts expressed as the probability that some SLAs are  
8 violated) and the expected excess quality for class  $i$  (i.e., the expected  
9 value of the difference between the delivered and contracted Quality of  
10 Service for class class  $i$ ). Clearly, there are many such risk measures  
11 136, which may be conceived. Alternatively, if the SLAs contain explicit  
12 penalties for noncompliance, risk can be measured as the expected  
13 penalty due to contract violations. Which risk measure 136 is more  
14 appropriate depends on the business implications of noncompliance: for  
15 large customers pursuing long-term relationships with the provider, the  
16 provider will strive to comply with all contracts, so he wishes to keep the  
17 probability of noncompliance at a low level. On the other hand, for  
18 small consumers frequently changing providers, the provider may  
19 deliberately risk contract violations, incorporating expected penalty as a  
20 cost in his profit function. Note that the current portfolio can be  
21 evaluated using the measured performance of the infrastructure, i.e., the  
22 Performance Evaluator 146 is a database of performance data. Such data  
23 is typically available from performance management studies or reports.

1 Determining risk measure 136a,  $r_s(\underline{y})$ , based on specified  
2 penalties is just one method to value the risk measure 136b,  $r_{QoS}(\underline{y})$ , in  
3 financial terms, called a *valuation method*. Alternative methods are  
4 conceivable including the use of quantified user satisfaction based on,  
5 for instance, surveys and experiments. This satisfaction might depend on  
6 the market segment (e.g., business and private customers), so that it  
7 would be necessary to assign different values to each such group of  
8 contracts. A second alternative is given below.

9 In step 80 of method 10, a provider finding out that his risk  
10 136b,  $r_{QoS}(\underline{y})$ , is not zero — he sometimes violates some SLAs — takes  
11 corrective action. In corrective action 92, he may re-engineer his  
12 infrastructure including increasing the capacity C or accept the risk and  
13 pay penalties, if such are specified, or accept unsatisfied customers.  
14 Contracts with particularly high Quality of Service guarantees require  
15 more resources to guarantee them. However, these high capacity  
16 requirements are offset when portfolio mixes such high Quality of  
17 Service requirement SLAs with contracts that offer only a low Quality of  
18 Service (e.g., a high loss rate) or a low probability of compliance. This  
19 leads either to a higher return, lower risk or lower price (or a  
20 combination therefore).

21 Referring now to FIG. 4, in corrective action 86, wherein  
22 relative compliance guarantees are used, the method 10 of the invention  
23 implements a service discipline 86b which allows the degradation the  
24 Quality of Service of a communication flow according the Quality of

1 Service specified in the corresponding SLA. The service discipline 86b  
2 is carried out by the network (assuming that it is possible to program the  
3 network for this purpose) Thus, the provider offers SLAs that guarantee  
4 relative compliance 86a. These relative compliance guarantees 86a are  
5 specified in terms of a noncompliance risk measure. In practice, a  
6 premium is charged for the higher compliance probability. Compliance is  
7 hence a product differentiator — a measure which may become as  
8 important as network reliability. Note that a portfolio  $\underline{y}$  containing SLAs  
9 with relative compliance guarantees 86a can be evaluated with the same  
10 approach to evaluate whether these relative compliance guarantees are  
11 met. Therefore, the method 10 provides this new contractual parameter,  
12 *relative compliance guarantees 86a*. The contractual parameter is  
13 calculated in step 70 of the method 10, in which the difference between  
14 the actual and the desired risk is equated to the relative compliance  
15 guarantee, which is added as a SLA contractual parameter, to define a  
16 lower service level. Making the risk explicit enables new valuation  
17 methods that, in particular, take advantage of the willingness of  
18 consumers to pay a certain amount for a given risk level.

#### 19 Compute the efficient frontier

20 Referring now to FIG. 7, portfolio theory is concerned with  
21 the computation and properties of the efficient frontier 110. Once the  
22 efficient frontier 110 has been determined, it is a business decision to  
23 select a portfolio on the efficient frontier, depending on the tolerable

1 level of risk or the target return.

2           In order for the provider to gain an insight into where his  
3 current portfolio stands with respect to an efficient portfolio that  
4 maximizes profit for a given risk, steps 60 and 62 of the method 10 apply  
5 the principals of Portfolio Theory to calculate the efficient frontier 110.  
6 FIG. 7 shows the return-risk space with the attainable portfolios and the  
7 set of efficient portfolios, i.e., the efficient frontier 110. The efficient  
8 frontier 110 is defined by a closed-form formula, which is only possible  
9 in special cases. Assessing the efficiency of the current portfolio P\*  
10 requires the computation of the efficient frontier 110. The example  
11 shown in the figure consists of three segments: two of them result from  
12 pairs of adjacent extremal points (shown in FIG. 9 , identified in a closer  
13 analysis of the quasi-linearity of the risk function in Portfolio Theory),  
14 and the third consists of portfolios of a single Quality of Service class.

15           It is assumed that return 134 is a linear function (as defined  
16 above), equal to the summation of the product of each vector describing  
17 the portfolio multiplied by nonnegative coefficients of a price vector  
18 associated with each vector describing the portfolio, from which  
19 marginal cost (a constant) is subtracted.

20           Risk measures 136 can be characterized as convex and  
21 quasi-linear risk functions. A function is called convex if all sublevel  
22 sets are strictly convex, which yields the following implication, *Lemma*  
23 *1*: If the risk measure is a convex risk function, then for every price  
24 vector and risk level, there exists a unique portfolio that maximizes

1 return at a given risk level. The function that describes the efficient  
 2 portfolios is continuous in both the certain risk level and in the price  
 3 vector. The amount of the asset in the unique portfolio is zero whenever  
 4 the price vector associated with that asset is also zero.

5           A risk function  $r$  is called quasi-linear if it depends only on  
 6 the two quantities, the summation of  $y_i$ , the vector description of an SLA  
 7 in a portfolio and the summation of the product of loss rate  $L_i$  for a  
 8 particular SLA  $i$  and  $y_i$ , for some vector  $\underline{L} = (L_1, \dots, L_n) \in \mathbf{R}_n^+$  which  
 9 characterizes the quality of each SLA (where the lower loss ratio  $L_i$   
 10 corresponds to better quality). Note that instead of  $\sum y_i$ , any linear  
 11 function  $\sum M_i y_i$  with positive coefficients  $M_i > 0$ , could have been used  
 12 because the transformation  $y_i \rightarrow M_i y_i$ ,  $p_i \rightarrow p_i M_i$  shows that this is  
 13 equivalent to the case where all  $M_i = 1$ . If risk is expressed in terms of a  
 14 special function of  $c$ , the inverse of the vector of an asset and the loss  
 15 ratio, then the condition that the partial derivative of the special function  
 16 with respect to  $c$  and the partial derivative with respect to the loss ratio  
 17 are less than zero ensures that the risk increases with the aggregate of  
 18 assets as well as with the quantity.

19           If  $n$ , the number of classes of SLAs, is less than 2, a  
 20 quasi-linear risk function cannot be convex in the same sense as  
 21 described above. The fact that the special function is convex provides  
 22 the best proxy of convexity for a quasi-linear risk function.

23           Referring now to FIG. 9, quasi-linearity has the following  
 24 consequence: *Lemma 2*: for a quasi-linear risk function, then (i) the

1 efficient frontier 110 is generated by portfolios consisting of one or two  
 2 classes of SLAs ; (ii) a portfolio consisting of one SLA  $i$  is efficient  
 3 only if  $(L_i, p_i)$ , the loss ratio for the SLA and the unit price for that SLA,  
 4 constitutes an extremal point on the graph of the price  $p(L)$  vs.  $L$ , loss  
 5 ratio shown in FIG. 9 , i.e., it lies on the boundary of the curve  
 6 representing the convex hull in the graph of price vs. loss ratio(therefore,  
 7 a portfolio of two SLAs,  $i$ , and  $j$ , is efficient only if  $(L_i, p_i)$  and  $(L_j, p_j)$  are  
 8 adjacent extremal points); (iii), supposing that the special function is  
 9 convex, then there exists a function that assigns to every price vector and  
 10 risk level greater than or equal to zero, an efficient portfolio of a certain  
 11 risk consisting of one or two SLAs; and (iv), for a number of SLAs  
 12 exceeding 2, a function as in “(iii)” cannot be continuous everywhere.

### 13 Model 1: Loss

14 Assuming that the Quality of Service is described by a  
 15 single parameter, the loss ratio  $L$ , defined as the proportion of lost bits to  
 16 sent bits in a given time interval of duration  $T$ , the relations developed  
 17 above can be illustrated with a real world example, Model 1, in which  
 18 the network consists of a single link of capacity  $C$ . This is useful due to  
 19 the fact that single links are important as access lines (e.g., an xDSL line  
 20 connecting a customer site with a central office) and hot spots, and will  
 21 be discussed in further detail below. Further, the method 10 assumes that  
 22 the network employees a proportional scheduling service discipline 86a  
 23 which ensures that whenever the aggregate condition, defined by the

1 total lost traffic being less than or equal to the summation of the product  
2 of the loss ratio  $L_j$  and the random variable,  $X_j$ , denoting the traffic sent  
3 by customers of class  $j$ , holds, the lost traffic for each contract does not  
4 exceed the specified loss ratio. Then, assuming further that there exists a  
5 random variable  $Y$  such that  $\sum X_i \sim (\sum y_i)Y$  and  $\sum L_i X_i \sim (\sum L_i y_i)Y$ , where  $\sim$   
6 denotes equality in distribution, then the risk function is quasi-linear  
7 (depending only on  $\sum y_i$  and  $\sum L_i y_i$ ). Therefore, the conclusions (i) and  
8 (ii) of *Lemma 2* hold, and one can conclude that the efficient frontier 110  
9 is generated by portfolios consisting of at most two Quality of Service  
10 classes  $L_i, L_j$  corresponding to adjacent extremal points on the price  
11 curve.

12 This is consistent with the findings for simple networks of  
13 Kai Cieliebbak and Beat Liver, in their provisional application in which  
14 it was shown that the efficient frontier 110 is generated by portfolios  
15 consisting of at most two Quality of Service classes,  $L_i, L_j$ , corresponding  
16 to adjacent (i.e., a line segment joining them is contained in the boundary  
17 of S) extremal points on the price curve of FIG. 9.

18 In case a network has conceptually a common queue of  
19 packets (with respect to the considered Quality of Service parameter), a  
20 proportional scheduling policy (with the above-described property) exists  
21 and hence Lemma 2 holds. Many broadcast network protocols have this  
22 property, so that someone skilled in the art can develop the required  
23 proportional scheduling policy. For example, the implementation of this  
24 policy for the CSMA/CD (Carrier Sense Multiple Access/Collision

Detection) is described as follows. First, each network node has to carry out admission control. Second, a network node uses the standard retransmits protocol for dealing with collisions if the lost traffic for class  $i$  exceeds the contracted loss ratio multiplied by the traffic sent by class  $i$  (i.e.,  $Z_i > \sum_l y_l$ ). Otherwise, packets are not retransmitted.

For non-broadcast networks, routing must be taken into account. The results for a single link apply only for special cases in which a network can be treated as a set of independent links. One way this can occur is if multiplexing among different flows is prevented. Another possibility is a highly symmetric topology that makes the network equivalent to independent Links as shown in FIG. 11. A ring network 160 consisting of four nodes 160a, 160b, 160c, and 160d, four links 162a, 162b, 162c, and 162d and two flows 164a and 164b between nodes 160a and 160c, and between 160b and 160d. Flow 164a is equally distributed over the two possible paths for Flow 164b, and vice versa. So, for multiplexing purposes, this network 160 is equivalent to a single link shared by the two flows 164a and 164b. In this figure, a dotted line represents aggregate flows  $X^j$ . In both paths, all links have the same capacity  $c_l$ . The capacity of the ring network 160 depends on  $X^{4,8}$ : If  $X^{4,8}$  varies between 0 and  $c_l$  and it is routed clock-wise, the capacity available to  $X^{1,3}$  and  $X^{5,3}$  varies between  $c_l$  and 0. Consequently,  $Z$  depends on the traffic situation.

Model 1 can be applied to real world networks. Networks fall into two broad categories: broadcast networks (e.g., Ethernet and



1 token ring) and networks using point-to-point connections. Some  
2 broadcast networks have conceptually a common queue of packets, i.e.,  
3 the shared medium may be treated like a single link. For such networks,  
4 the equations for noncompliance risk with loss guarantees and expected  
5 penalty for loss, given below, apply. In fact, there exists a large  
6 number of broadcast networks that can be modeled as a single link.  
7 These include Carrier Sense Multiple Access (CSMA), CSMA/CD  
8 (Collision Detection) – better known as Ethernet, token buses and rings,  
9 wireless networks, and satellite up-links.

#### 10 Quantify risk and return of the current portfolio

11 In the fourth step 66 of method 10, formulas for risk  
12 measures are called for. Two specific formulas for quasi-linear risk  
13 measures may now be provided. First, the following definitions are  
14 made:  $y = \sum_i y_i$ ;  $c = C/y$ ;  $L = (\sum_i y_i/y)$ , and the random distributions are  
15 written as  $Z = (X - C)^+ \sim (yY - C)^+ = y(Y - c)^+$ ,  $\sum_i X_i \sim (\sum_i y_i)Y = LY$ .

16 The probability of noncompliance with loss guarantees equals  $PNL(c, L)$   
17  $= P[Z > \sum_i X_i] = P[(Y - c)^+ - LY > 0]$ . (1)

18 This measure 136 defines the portfolio risk that is the  
19 probability that some SLA of the portfolio is violated. Here the pair of  
20 variables  $(y, \sum_i y_i)$  has been replaced with the equivalent pair  $(c, L)$ . The  
21 probability of noncompliance can be computed from this formula once

1 the distribution of  $Y$  is known (e.g., from historical data).  
 2 Making the reasonable assumption that the aggregate  
 3 penalty for noncompliance is proportional to the lost traffic in excess of  
 4 the SLAs,  $Z - \sum_i X_i$ , then the expected penalty for loss equals:

$$5 \quad EPL(c, L) = (\beta C)E[Z - \sum_i X_i], \quad (2)$$

6 for some constant  $\beta > 0$ , so that  $(\beta C)$  denotes the penalty per capacity  
 7 unit.

## 8 Model 2: Delay

9 In this section, a second model, Model 2, is described that is  
 10 complementary to the previous one, based on the following two basic  
 11 assumptions, namely, (1) a single link and (2) the Quality of Service is  
 12 described by a single parameter, the delay  $D$ . Assume that the link serves  
 13 customers of guaranteed delays  $D_1 < \dots < D_n$ . As in the preceding  
 14 sections, the service discipline is activated which customers of class  $i$   
 15 have strict priority over customers of class  $j > i$  (head-of-line), but  
 16 service in progress is not interrupted (i.e., non-preemptive).

17 In contrast to the preceding sections, where a general  
 18 scaling assumption was sufficient, here a specific traffic distribution  
 19 must be assumed: customers of class  $i$  arrive at Poisson rate  $\lambda_i$ , and the  
 20 arrival processes are independent of each other. Further, service times  
 21 are identically distributed and they are independent of each other and of

1 the arrival processes (M/G/1 queuing system).

2 Under the assumptions that the network consists of one link  
3 of capacity  $C$ , the Quality of Service is described by a single parameter  
4 (the delay  $D$ ) and the assumption in the above paragraph, the expected  
5 penalty for delay,  $EPD(c, D)$ , is a quasi-linear risk function that is  
6 convex. Therefore, conclusions (i) and (iii) of *Lemma 2* hold: The  
7 efficient frontier 110 is generated by portfolios consisting of at most two  
8 Quality of Service classes  $D_i, D_j$  corresponding to adjacent extremal  
9 points on the price curve. Moreover, there exists a function  $v^o(p)$  that  
10 assigns to every risk  $\rho$  and price vector  $p$  a portfolio of at most two  
11 Quality of Service classes, which is continuous except at price vectors  
12 where the set of extremal points changes.

13 The expected penalty for delay, EPD is computed over a  
14 time interval from the formula:  $EPD(c, L) = \beta \sum \{(\lambda_i / \mu)(E[W_i] - D_i)\} =$   
15  $\beta \{ (\alpha / (c-1)) - (D/c) \}$ , where  $\beta$  is a constant  $> 0$ ,  $c = 1 / \sum (\lambda_i / \mu)$ ,  $D = c \sum$   
16  $\{(\lambda_i / \mu) D_i\}$ , and  $E[W_i]$  denotes the expected waiting time (i.e., delay) for  
17 class  $i$ . Assuming that class  $i$  traffic arrives at Poisson rate  $\lambda_i$ , and the  
18 arrival process are independent of each other; service times,  
19 characterized by service rate  $\mu$  of class  $i$ , are independently distributed,  
20 and they are independent of each other and of the arrival processes —  
21 i.e., an M/G/1 queuing system is assumed. Assuming that the service  
22 times for customers of all classes are distributed as a random variable  $Y$   
23 of mean  $\mu$  then  $\alpha = (1 + \{Var[Y] / \mu^2\}) / 2$ , where  $Var[Y]$  denotes the  
24 variance of random variable  $Y$ . Note that noncompliance is defined here

1 in terms of a penalty for exceeding  $D_i$  and a premium for remaining  
2 under  $D_i$ .

3 Determine base-line portfolios for (cost-based) zero-profit prices

4 In step 62 of method 10, determining base-line scenarios, is  
5 useful to provide insights in the economics of a network's operation. The  
6 method 10 optionally calculates a base-line efficient frontier (or  
7 portfolio), assuming that there exists sufficient demand for all  
8 considered Quality of Service classes. This means that  $\mathbf{R}^n_+$  defines the  
9 set of attainable portfolios. A provider would most likely wish to  
10 determine the base-line efficient frontier first. Then, he can investigate  
11 which of these portfolios are probably attainable and compare the  
12 base-line prices against markets prices (e.g., to determine which Quality  
13 of Service classes to offer).

14 For base lining, the prices  $p_i$  can be defined as zero-profit  
15 prices at the risk level  $EPL(c, L)=0$  — so that profit equals costs — by  
16 setting prices proportional to the resource consumption of the services.  
17 For this purpose, a provider would calculate for a given risk level  $\rho$  and  
18 Quality of Service class  $L$ , the maximal number of contracts  $y_{\rho,L}$  he can  
19 accept. This yields the profit  $e = p y_{\rho,L} - p_{C,C}$ , so that the zero-profit price is  
20  $p = p_{C,C} / y_{\rho,L}$ . The provider is able to offer QoS types profitable if the  
21 zero-profit price is equal or lower than market prices. Note that the  
22 reverse does not hold, because multiplexing different QoS classes  
23 increases often the network utilization and, in turn, reduces the costs.

1 Multiplexing gains (among different QoS types) result in portfolios with  
2  $e(y) > 0$ . In case that some zero-profit prices are above the market  
3 prices, a portfolio  $y$  can be considered if the amount  $e(y)$  can be used to  
4 reduce the prices of contracts that have zero-profit prices above market  
5 prices. If a provider calculates the efficient frontier, he would usually  
6 eliminate the portfolios from the frontier where he would expect  $e(y) <$   
7  $0$ . The reason is that in case  $e(y) < 0$ , the network exhibits negative  
8 multiplexing gains (i.e., the assuming usage pattern cannot be allocated  
9 efficiently), the network is not well suited for offering such  
10 combinations of QoS classes and, hence, such combinations should not  
11 be offered. A prospective provider might calculate the zero-profit prices  
12 (i.e., the prices that cover costs) and the resulting base-line efficient  
13 frontier. He could then compare these zero-profit prices of SLAs  
14 belonging to efficient portfolios with the market prices: if all zero-profit  
15 prices associated with each portfolio are, for instance, above the market  
16 prices, the provider is not competitive. For a particular portfolio  
17 (assuming no other financial subsidies), the losses of due contracts with  
18 zero-profit prices that are higher than market prices have to be  
19 compensated by profits due to contracts with lower zero-profit prices  
20 than market prices.

21 Derive strategies to move towards a more efficient portfolio

22 Referring again to FIGS. 4 and 7, in order to achieve a more  
23 efficient portfolio (depicted by the arrow pointing from the current

1 portfolio  $P^*$  to the efficient frontier), several options 80 for corrective  
 2 action are possible. In corrective action 84, a service provider might  
 3 reduce costs or increase risk. For this purpose, the degree of  
 4 multiplexing could be increased or the network capacity  $C$  decreased.  
 5 Note that it is sometimes possible to increase the multiplexing without  
 6 modifying the risk. Such a method is described by Kurz, Thiran, and  
 7 LeBoudec, in an article entitled *Regulation of a connection admission*  
 8 *control algorithm* in the Proceedings of INFOCOM'99. In corrective  
 9 action 82, a provider might adopt a marketing strategy to move towards a  
 10 more efficient portfolio. For instance, the price of the low-quality  
 11 service could be reduced to increase the number of contracts in this  
 12 class. In corrective action 92, providers might trade risks (analog to load  
 13 securitization and syndication): a provider can buy and sell contracts to  
 14 optimize his portfolio assuming that there exists a market for trading  
 15 contracts. For trading risks, the operator determines the number of  
 16 to-be-traded contracts of class  $i$ ,  $\Delta_i = y_i - y_i^*$ , where  $y_i^*$  and  $y_i$  denote the  
 17 number of contracts of class  $i$  in case of the current portfolio and a  
 18 desirable (i.e., efficient) portfolio, respectively. If  $\Delta_i > 0$ , it's necessary  
 19 buy  $\Delta_i$  contracts of class  $i$ , and if  $\Delta_i < 0$  the provider sells this number  
 20 of contracts of class  $i$ . Note that trading is a corrective action that leads  
 21 to an efficient portfolio (assuming that the necessary trades can be  
 22 executed, i.e., that there is adequate supply of SLAs having the  
 23 appropriate characteristics and a means of purchasing these SLAs).

24 An advantage of the invention is that it automatically and

1 rapidly calculates risk and estimated performance in transactions  
2 involving network service level agreements.

3 Another advantage of the invention is that the consumer  
4 may be offered a wider variety of services at a reduced price, due to the  
5 associated reduction of risk brought about by better understanding of  
6 risk levels for each class of services offered.

7 A latitude of modification, change, and substitution is  
8 intended in the foregoing disclosure and in some instances, some  
9 features of the invention will be employed without a corresponding use  
10 of the other features. Accordingly, it is appropriate that the appended  
11 claims be construed broadly and in a manner consistent with the scope of  
12 the invention.

1    WHAT IS CLAIMED IS:

2        1. A method for managing operational risk and return of a production  
3        infrastructure with respect to a current portfolio of service-level  
4        agreements, the method comprising:

- 5            a. calculating an efficient frontier that identifies efficient  
6            portfolios of SLAs using inputs such as characteristics of  
7            the production infrastructure, traffic and QoS characteristics  
8            and the price of each class of SLAs;  
9            b. optionally, calculating a baseline efficient frontier using  
10           inputs such as market pricing and break-even pricing;  
11           c. determining the performance of the current portfolio of  
12           SLAs using a portfolio evaluator means and inputs which  
13           characterize the current portfolio; and  
14           d. evaluating performance by comparing the current portfolio  
15           and the efficient portfolios with the desired level of risk and  
16           return; and, if desired, implementing corrective action based  
17           on any desired risk and return.

18        2. The method of claim 1, wherein the corrective action is selected  
19        from a group of possible actions consisting of:

- 20            a. adjusting marketing strategy;  
21            b. changing the degree of multiplexing in the network;  
22            c. changing network capacity;



- 1           d. changing the cost of network capacity;
- 2           e. defining relative compliance guarantees where networks
- 3           support definition of adequate policies on the basis of
- 4           priority;
- 5           f. changing prices and comparing with baseline prices of
- 6           SLAs; and
- 7           g. trading contracts of different classes of SLAs.

8       3. The method of claim 1 or claim 2 wherein, after corrective action is  
9       taken, the method takes new inputs, and, with the exception of the  
10      corrective action of trading SLAs, the method is re-executed, by  
11      calculating a new efficient frontier which is compared with  
12      performance of the current portfolio, calculated by the portfolio  
13      evaluator means.

14  
15      4. The method of claim 2 wherein, for trading risk, the operator  
16      determines the number of to-be-traded SLAs of a certain class by  
17      subtracting the number of SLAs of the certain class in the current  
18      portfolio from the number of SLAs in a desired portfolio, and taking  
19      action that tends to narrow the difference; thus moving the contents  
20      of the current portfolio to that of an optimal portfolio.

21      5. A method for managing operational risk and return with respect to  
22      a portfolio of service-level agreements, wherein the method uses a

noncompliance risk measure to calculate risk; and wherein, principals of portfolio theory are applied to characterize the portfolio for comparison with other possible portfolios.

6. The method of claim 5, wherein the risk measure is selected from a group of quasi-linear noncompliance risk measures, the group consisting of a probability of noncompliance with loss guarantees, a probability of noncompliance with delay guarantees, an expected penalty for loss, and an expected penalty for delay.

7. The method of claim 5 wherein the risk measure is quasi-linear and the principals of portfolio theory are applied to calculate an efficient frontier, thus enabling a provider to select an efficient portfolio that maximizes return for a given risk or minimizes risk for a given return.

8. The method of claim 5, wherein the risk function is given by a probability of noncompliance with loss guarantees,  $PNL$ , which, once the distribution of  $Y$ , a common random variable, which represents service times for customers of all classes, is known such as through historical data, the method computes from the formula:  $PNL(c, L) = P[(Y-c)^+ - LY > 0]$ , where  $c$  is  $C/\underline{y}$ ,  $\underline{y}$  is the summation of a total amount of accepted bandwidths of Quality of Service class  $L_i$ ,  $C$  is overall capacity of the network,  $\underline{L}$  is a vector which characterizes the quality of each SLA, and  $P[\underline{x}]$  denotes the probability of  $\underline{x}$ .

9. The method of claim 5, wherein the risk function is given by an expected penalty for loss,  $EPL$ , which the method computes over a time interval from the formula:  $EPL(c, L) = (\beta C) \{E[(Y-c)^+]-LE[Y]\}$ , where  $c$  is  $C/\underline{y}$ ,  $\underline{y}$  is the summation of the total amount of accepted bandwidths of Quality of Service class  $L_i$ ,  $C$  is overall capacity of the network,  $L$  is a vector which characterizes the quality of each SLA,  $\beta$  is a constant  $>0$ , so that  $(\beta C)$  denotes the penalty per capacity unit,  $E$  is statistical expectation, and  $L_i$  is a total of Quality of Service offered by class  $i$ .

10. The method of claim 5, wherein the risk function is given by an expected penalty for delay,  $EPD$ , which the method computes over a time interval from the formula:  $EPD(c, L) = \beta \{ (\alpha/(c-1)) - (D/c) \}$ , where  $\beta$  is a constant  $> 0$ ,  $c = 1/\Sigma(\lambda/\mu)$ ,  $D = c \Sigma \{ (\lambda/\mu) D_i \}$ , and  $E[W_i]$  denotes the expected waiting time (i.e., delay) for class  $i$ , wherein further, assumptions are made that class  $i$  traffic arrives at Poisson rate  $\lambda_i$ , and that arrival processes are independent of each other; service times, characterized by service rate  $\mu$  of class  $i$ , are independently distributed and independent of each other and of the arrival processes; that  $\alpha = (1 + \{Var[Y]/\mu^2\})/2$  given that service times for customers of all classes are distributed as a random variable  $Y$  of mean  $\mu$  where  $Var[Y]$  denotes the variance of random variable  $Y$ , and wherein noncompliance is a penalty for exceeding  $D_i$  and a

1 premium for remaining under  $D_i$ .

2 11. The method of claim 5, wherein the risk function is given by an  
3 expected penalty for delay,  $EPD$ , which the method computes,  
4 assuming Poisson traffic, from the formula:  $EPD(\mathbf{v}) = \beta \sum_i (E[W_i] -$   
5  $D_i)$ , where  $\mathbf{v}$  is a vector of traffic intensities,  $v_i$  is the traffic intensity  
6 of customers in class  $i$ ,  $E$  is statistical expectation,  $\beta$  is a constant  $>0$   
7 so that  $\beta C$  denotes the penalty per capacity unit,  $W_i$  is waiting time  
8 for a class  $i$ , and  $D_i$  is the maximum permissible delay for a class  $i$  of  
9 SLAs.

10 12. A method for determining risk and return of a production  
11 infrastructure with respect to a current portfolio, the method  
12 calculating a selected risk, such as a financial risk or Quality of  
13 Service risk and comprising:

- 14 a. invoking a performance evaluator means, to determine an  
15 expected actual Quality of Service provided by a network  
16 given a set of contracts with associated traffic descriptors;  
17 b. calculating portfolio risk, based on the actual Quality of  
18 Service and the contracted Quality of Service of the  
19 contracts of the portfolio using a risk measure  
20 corresponding to the selected risk; and  
21 c. computing return according to the formula  $p_i y_i - p_c C$  for  
22 capacity  $C$ , expected revenue  $p_i$ , amount of contracts of

1 type  $i$ ,  $y_i$ , and unit price for capacity  $C$ ,  $p_C$ , where  $C$  is both  
2 an input in the performance evaluator and a characteristic of  
3 the production infrastructure.

4 13. The method of claim 12 wherein the performance evaluator means  
5 is selected from a group of performance evaluator means consisting  
6 of a formula, a simulator or test system, and a measurement system  
7 for the production system.

8 14. A computerized system encoded with a method having an  
9 associated process flow, the method managing the risk of financial  
10 loss due to penalties brought on by noncompliance with respect to  
11 network service-level agreements, characterized in that the method  
12 executes the following steps:  
13 a. gathering information such as traffic statistics, price  
14 information, and network information;  
15 b. inputting the gathered information into a risk and a return  
16 function, yielding risk and return;  
17 c. calculating an efficient frontier; and  
18 d. using the efficient frontiers to identify an optimum portfolio  
19 of service level agreements, based on a maximum level of  
20 return for a given risk or a minimum risk for a given level of  
21 return.

15. The system of claim 14, wherein, in the method, after an optimum portfolio is identified, trading service-level agreements in order to arrive at an optimum portfolio, the number of agreements of a certain class to be traded being determined by subtracting the number of SLAs of the certain class in the current portfolio from the number of SLAs in a desired portfolio, and taking action that tends to narrow the difference, thus moving the contents of the current portfolio to that of an optimal portfolio

16. The system of claim 14, wherein, in the method, the risk function is given by a probability of noncompliance with loss guarantees,  $PNL$ , which, once the distribution of  $Y$ , a common random variable which represents the service times for customers of all classes is known such as through historical data, the method computes from the formula:  $PNL(c, L) = P[(Y-c)^+ - LY > 0]$ , where  $c$  is  $C/\underline{y}$ ,  $\underline{y}$  is the summation of a total amount of accepted bandwidths of Quality of Service class  $L$ ,  $C$  is overall capacity of the network,  $\underline{L}$  is a vector which characterizes the quality of each SLA, and  $P[\underline{x}]$  denotes the probability of  $\underline{x}$ .

17. The system of claim 14, wherein, in the method, the risk function is given by an expected penalty for loss,  $EPL$ , which the method computes over a time interval from the formula:  $EPL(c, L) = (\beta C) \{E[(Y-c)^+] - LE[Y]\}$ , where  $c$  is  $C/\underline{y}$ ,  $\underline{y}$  is a summation of a total

amount of accepted bandwidths of Quality of Service class  $L$ ,  $C$  is overall capacity of the network,  $\underline{L}$  is a vector which characterizes the quality of each SLA,  $\beta$  is a constant  $> 0$ , so that  $(\beta C)$  denotes the penalty per capacity unit,  $E$  is statistical expectation, and  $L_i$  is the total Quality of Service offered by class  $i$ .

18. The system of claim 14, wherein, in the method, the risk function is given by an expected penalty for delay,  $EPD$ , which the method computes over a time interval from the formula:  $EPD(c, L) = \beta \{ (\alpha / (c-1)) - (D/c) \}$ , where  $\beta$  is a constant  $> 0$ ,  $c = 1 / \Sigma(\lambda_i / \mu_i)$ ,  $D = c \Sigma \{ (\lambda_i / \mu_i) D_i \}$ , and  $E[W_i]$  denotes the expected waiting time (i.e., delay) for class  $i$ , wherein further, assumptions are made that class  $i$  traffic arrives at Poisson rate  $\lambda_i$ , and that arrival processes are independent of each other; service times, characterized by service rate  $\mu$  of class  $i$ , are independently distributed and independent of each other and of the arrival processes; that  $\alpha = (1 + \{Var[Y] / \mu^2\}^2) / 2$  given that service times for customers of all classes are distributed as a random variable  $Y$  of mean  $\mu$  where  $Var[Y]$  denotes the variance of random variable  $Y$ , and wherein noncompliance is a penalty for exceeding  $D_i$  and a premium for remaining under  $D_i$ .

19. The system of claim 14, wherein, in the method, the risk function is given by an expected penalty for delay,  $EPD$ , which the method computes, assuming Poisson traffic, from the formula:  $EPD(v) =$

1  $\beta \sum_i (E[W_i] - D_i)$ , where  $\mathbf{v}$  is a vector of traffic intensities,  $v_i$  is the  
 2 traffic intensity of customers in class  $i$ ,  $E$  is statistical expectation,  $\beta$   
 3 is a constant  $>0$  so that  $\beta C$  denotes the penalty per capacity unit,  $W_i$   
 4 is waiting time for a class  $i$ , and  $D_i$  is the maximum permissible delay  
 5 for a class  $i$  of SLAs.

6 20. A computerized system encoded with a method which manages  
 7 operational risk and return with respect to network service-level  
 8 agreements, wherein the method calculates a probability of actual loss  
 9 higher than allowed by a contract and a return, and, applying the  
 10 principals of portfolio theory, determines an efficient frontier to  
 11 enable the selection of an efficient portfolio that maximizes return at  
 12 a given risk or minimizes risk at a given return.

13 21. The system of claim 20 wherein, in the method, the return is  
 14 calculated using an expected penalty for loss.

15 22. A computerized system, encoded with a method executing a  
 16 process flow which manages operational risk and return with respect  
 17 to network service-level agreements, operating over a computer  
 18 network comprising a plurality of interconnected computers and a  
 19 plurality of resources, each computer including a processor, memory  
 20 and input/output devices, each resource operatively coupled to at  
 21 least one of the computers and executing at least one of the activities



1 in the process flow, wherein the method manages a portfolio of  
 2 service level agreements, each of which define a service level, a  
 3 connection, a contract duration, traffic descriptors, quality of service  
 4 guarantees and a probability of noncompliance with respect to the  
 5 quality of service guarantees, the probability of noncompliance  
 6 providing a contractual parameter wherein, after being accepted by a  
 7 customer, noncompliance within the contracted limits does not trigger  
 8 a penalty, thus avoiding penalties for noncompliance and thus  
 9 reducing.

10 23. The system of claim 22, wherein, the quality of service guarantees  
 11 include loss rate, delay, and jitter.

12 24. A computerized system encoded with a method which manages  
 13 operational risk and return with respect to service-level agreements in  
 14 a network, wherein the method manages a portfolio of service level  
 15 agreements of at least two classes each of which representing relative  
 16 compliance guarantees, wherein, a customer subscribing to a higher  
 17 relative compliance guarantee has priority with respect to resources in  
 18 the network, over customers having a lower relative compliance  
 19 guarantee.

20 25. A computerized system encoded with a method which manages

1 operational risk and return with respect to network service-level  
2 agreements, wherein the method takes probabilities of noncompliance  
3 and base-line prices, and, through the application of portfolio theory,  
4 calculates an efficient portfolio of service-level agreements, thus  
5 providing a network administrator with insights into the economics of  
6 a network's operations which can be used to modify the terms of  
7 standard service-level agreements.

8 26. The system of claim 25, wherein the base-line prices are  
9 zero-profit prices.

10 27. The system of claim 25, wherein the base-line prices are market  
11 prices.

12 28. The system of claim 26, wherein the zero-profit prices are  
13 calculated by:

- 14 a. calculating a base-line efficient portfolio using market  
15 pricing and thus determining base-line prices;
- 16 b. investigating which of these portfolios are probably  
17 attainable;
- 18 c. comparing the base-line prices against a zero-profit price;
- 19 d. if the zero-profit price is higher than the base-line price,  
20 taking corrective action.

1 Portfolio Theory Method of Managing Operational Risk  
2 with Respect to Network Service-level Agreements

3 Abstract of the Invention

4 A method for managing operational risk and return with respect to a  
5 portfolio of service-level agreements is provided, wherein the method  
6 uses a noncompliance risk measure to calculate risk; and wherein,  
7 principals of portfolio theory are applied to characterize the portfolio for  
8 comparison with other possible portfolios.

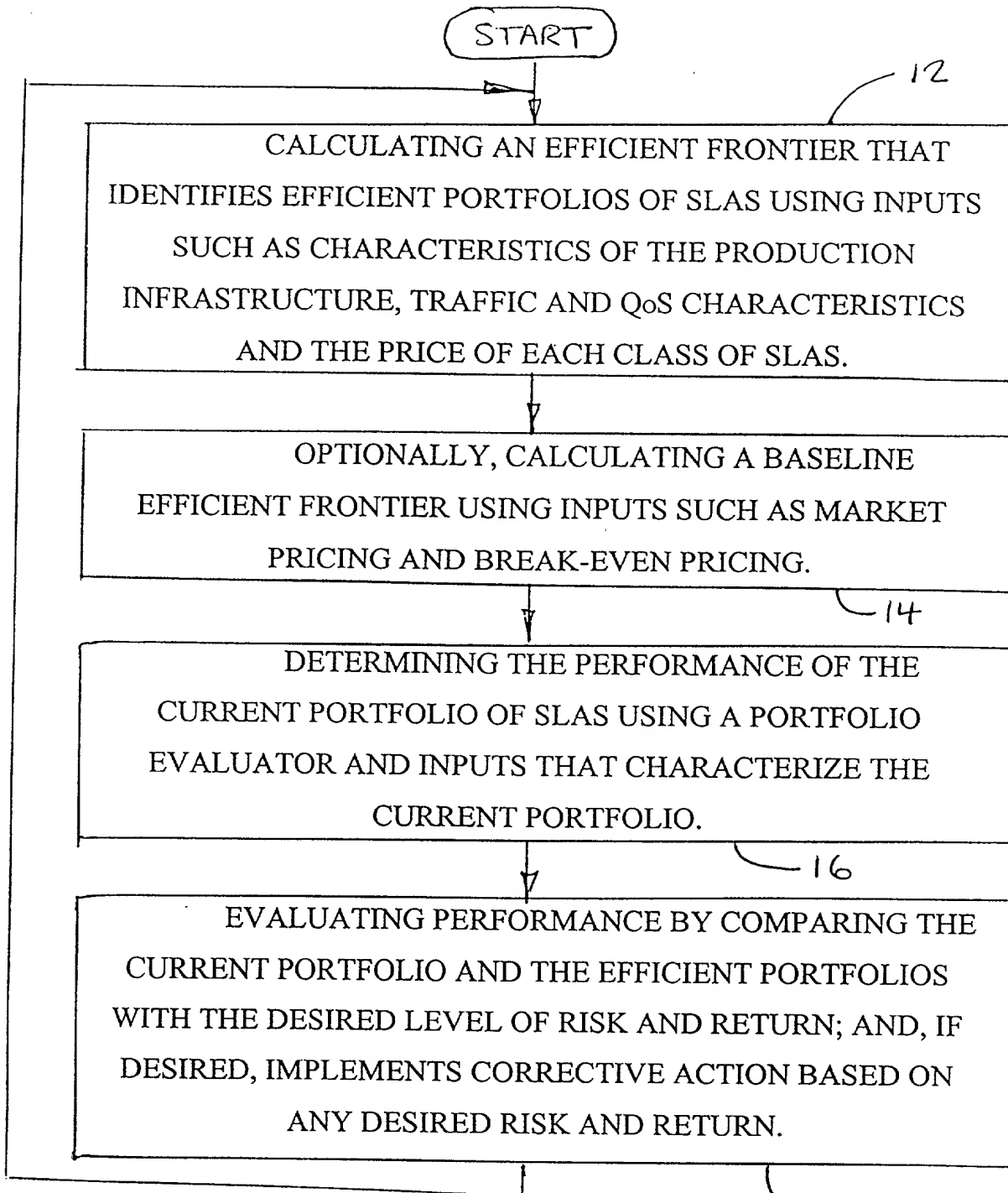


FIG. 1

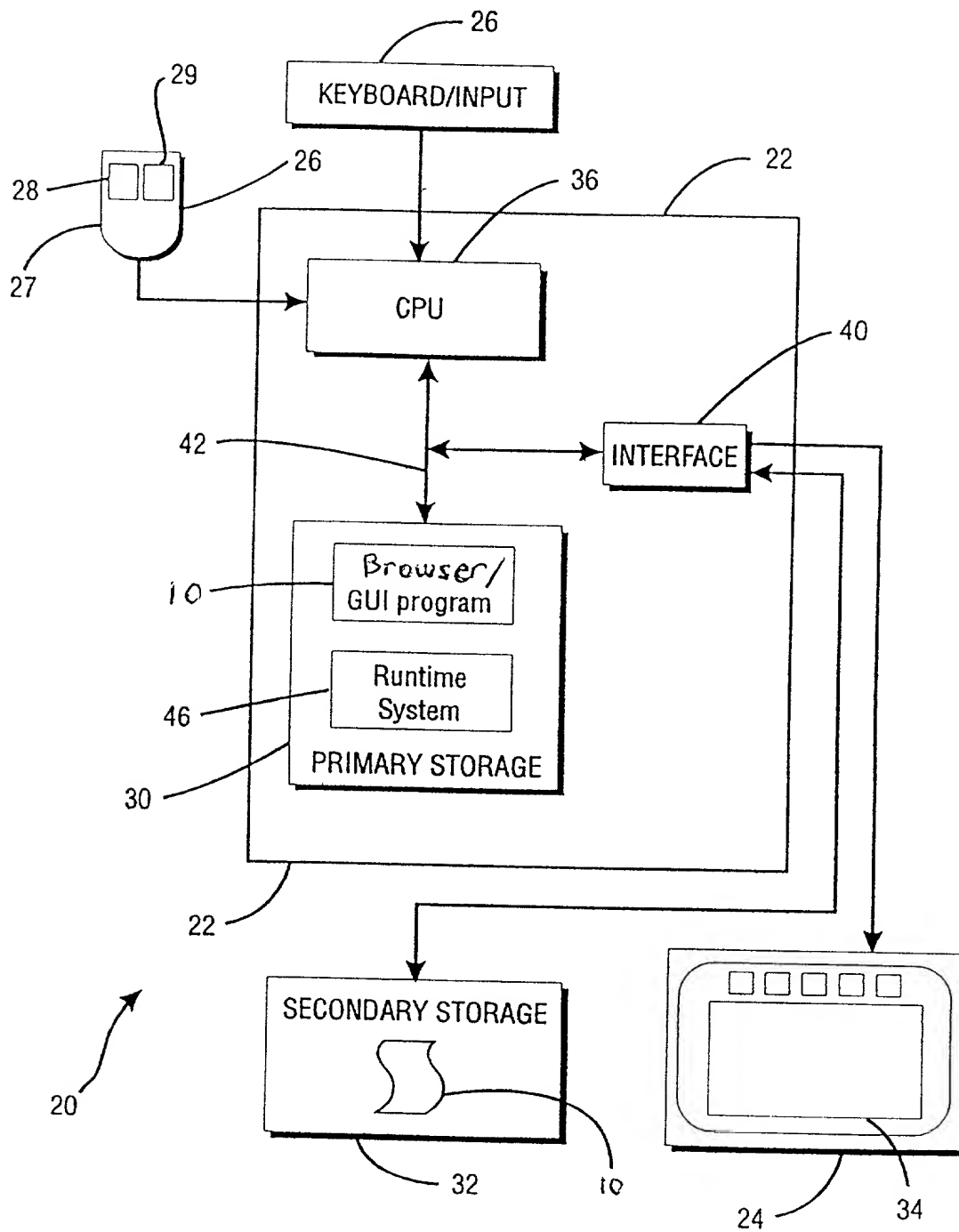


FIG. 2

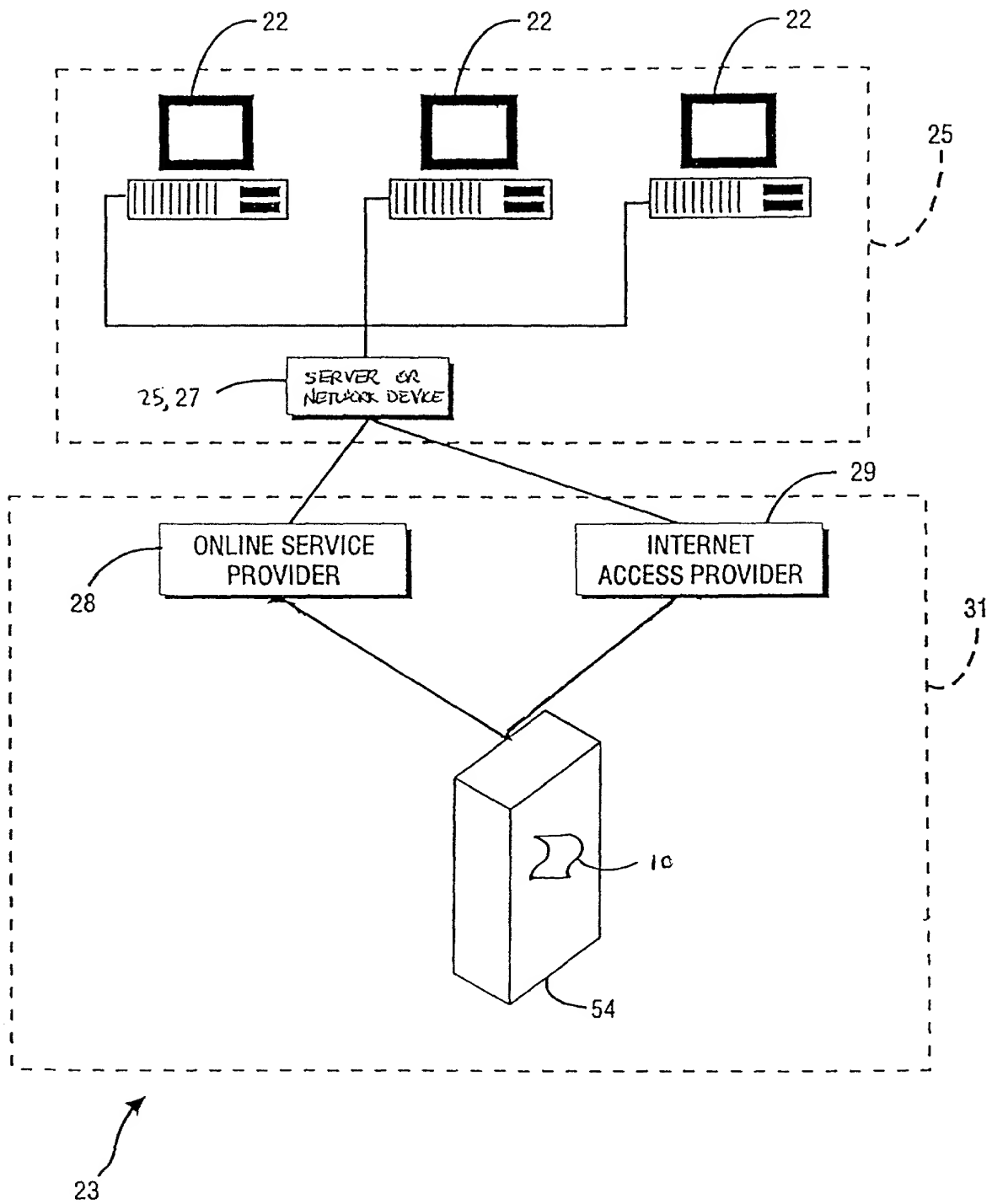


FIG. 3

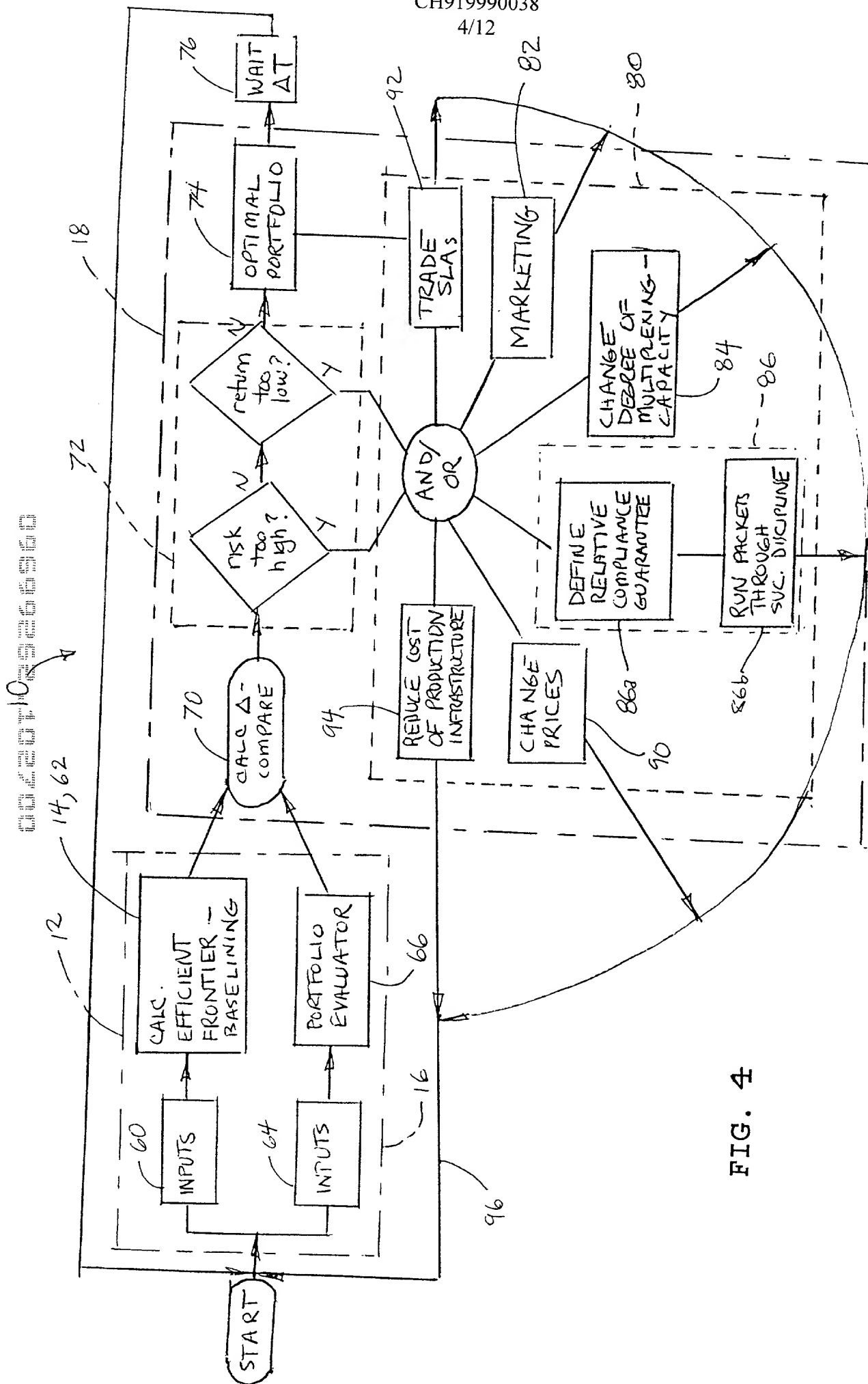


FIG. 4

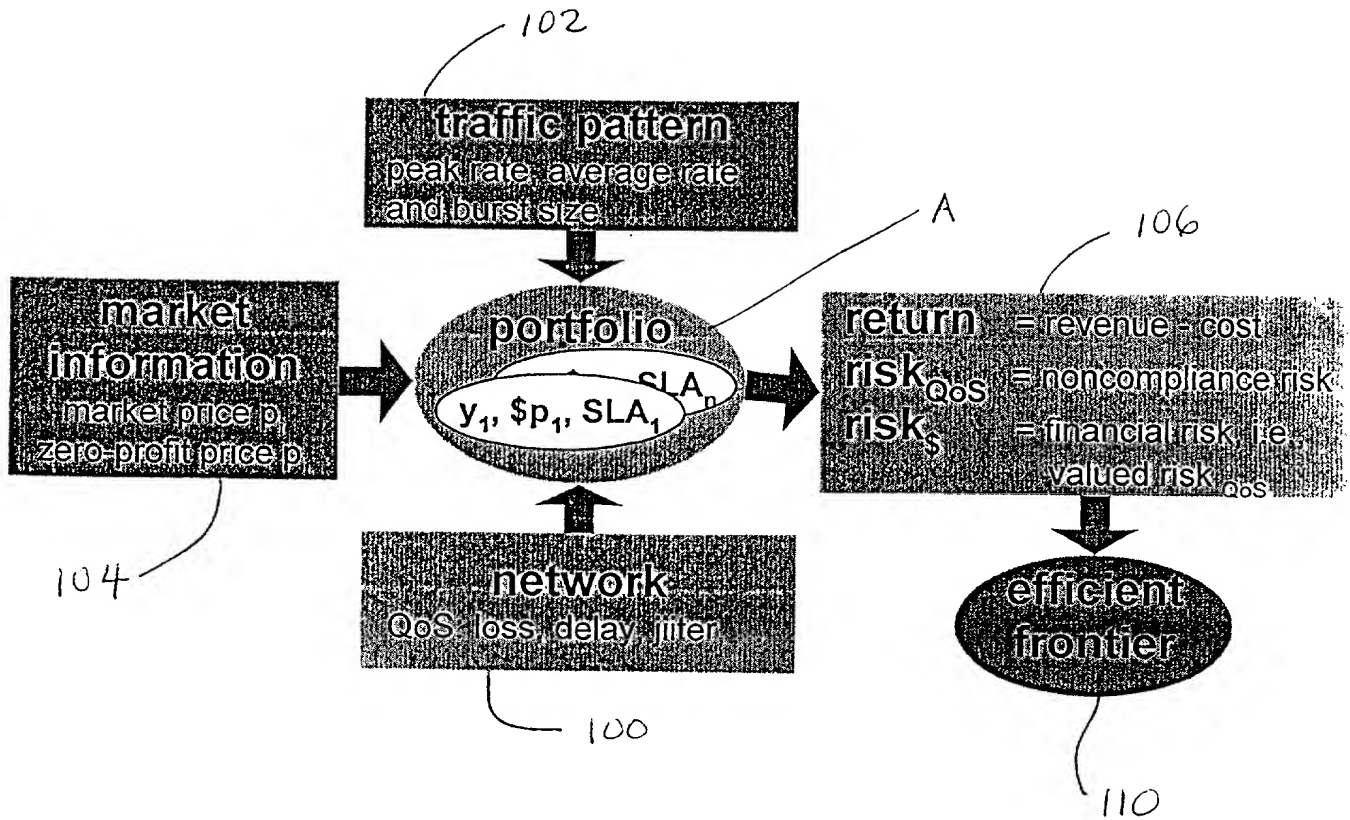


FIG. 5



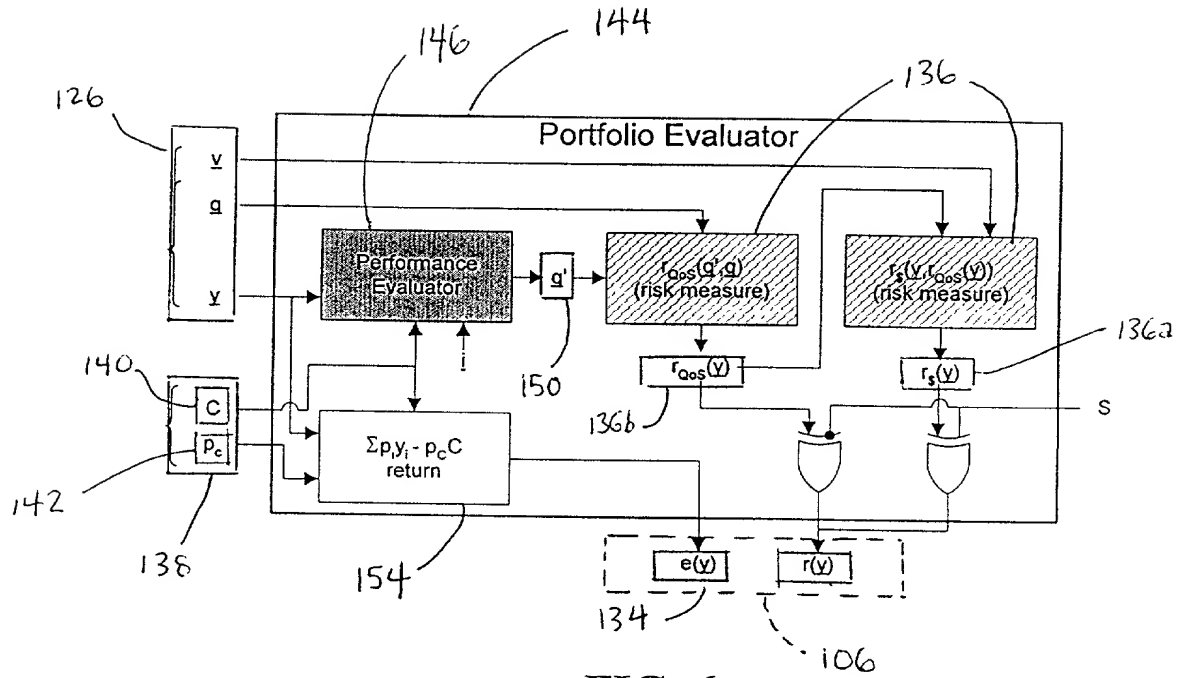


FIG. 6

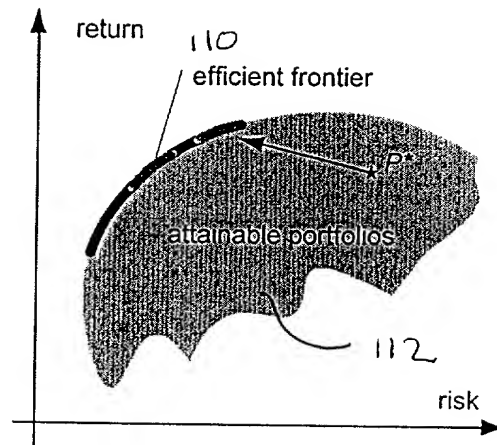


FIG. 7

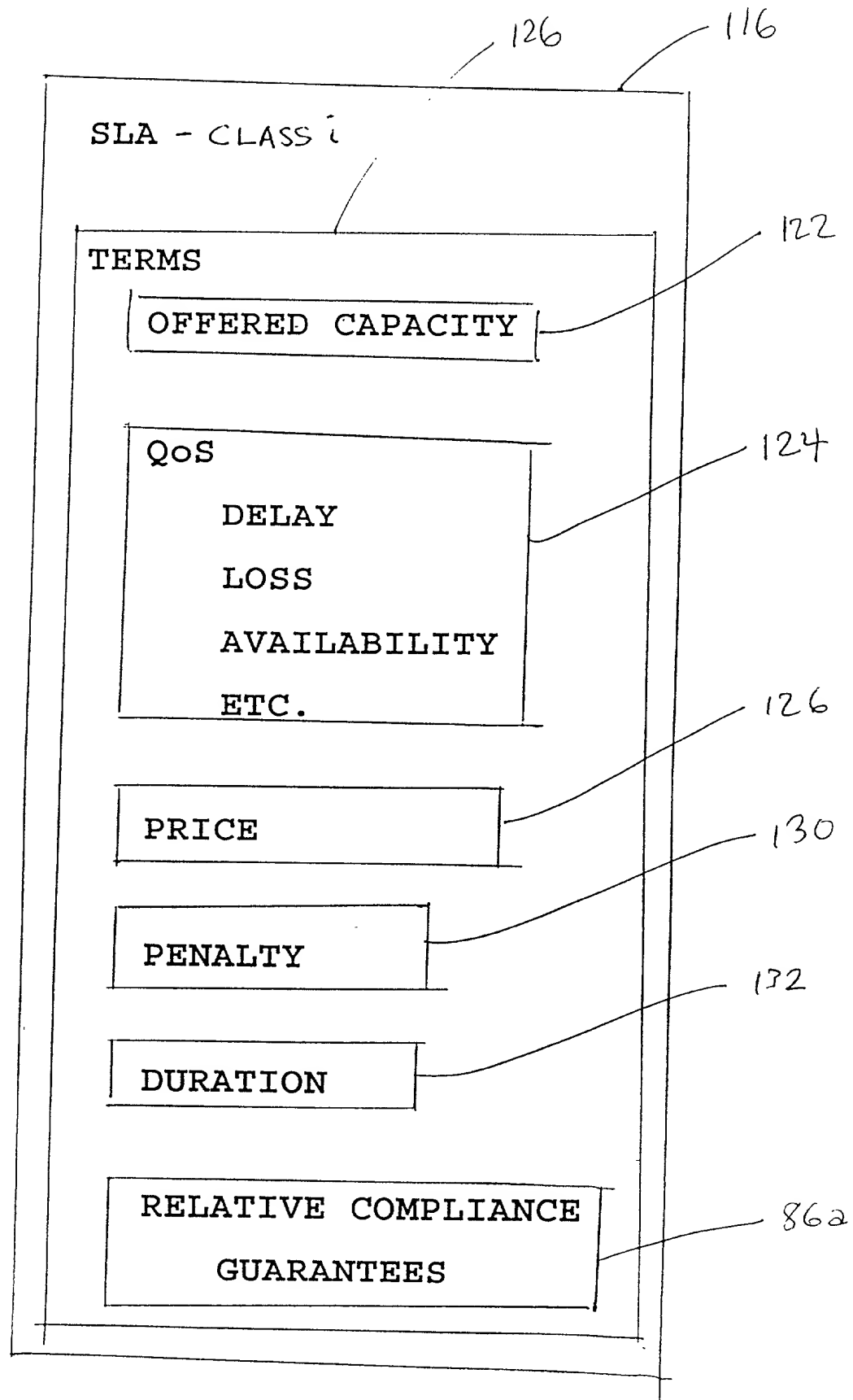


FIG. 8

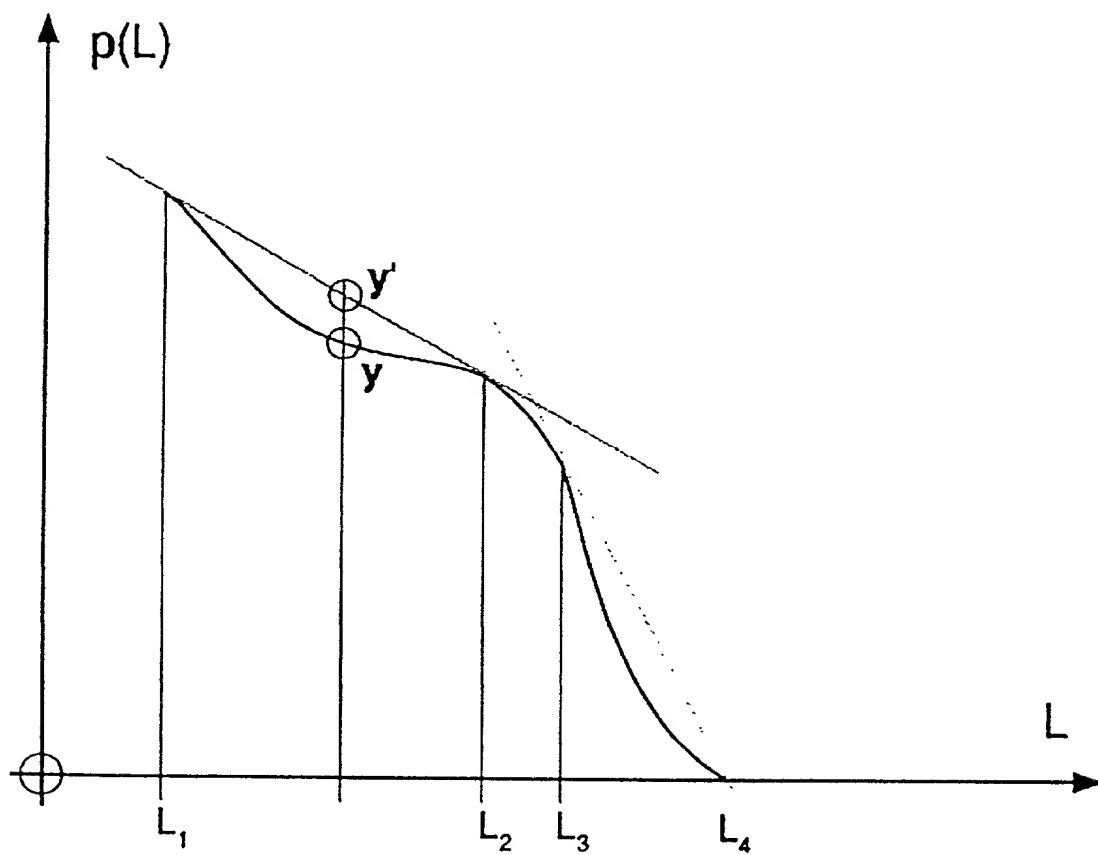


FIG. 9

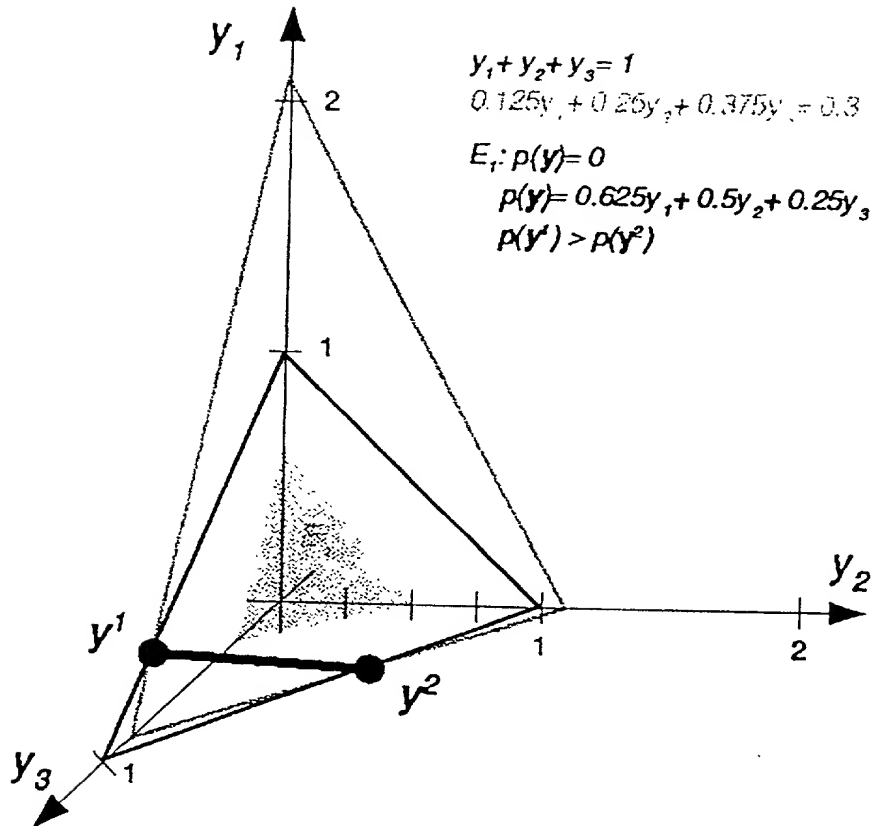


FIG. 10

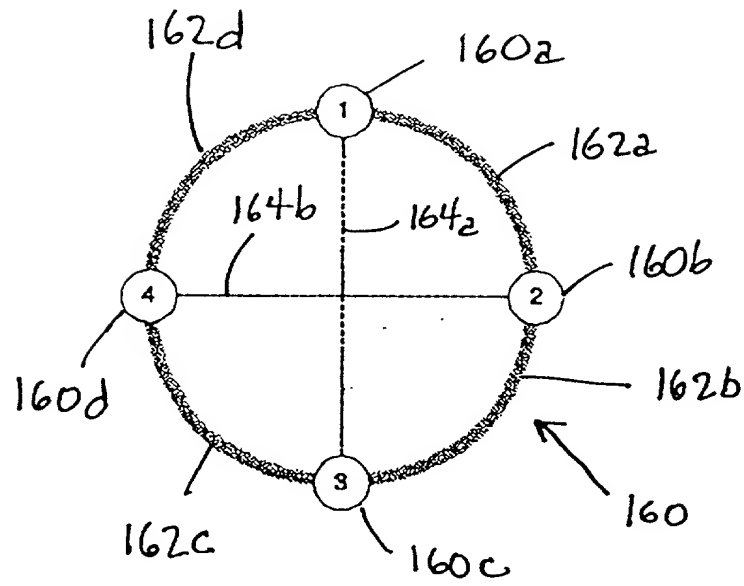


FIG. 11

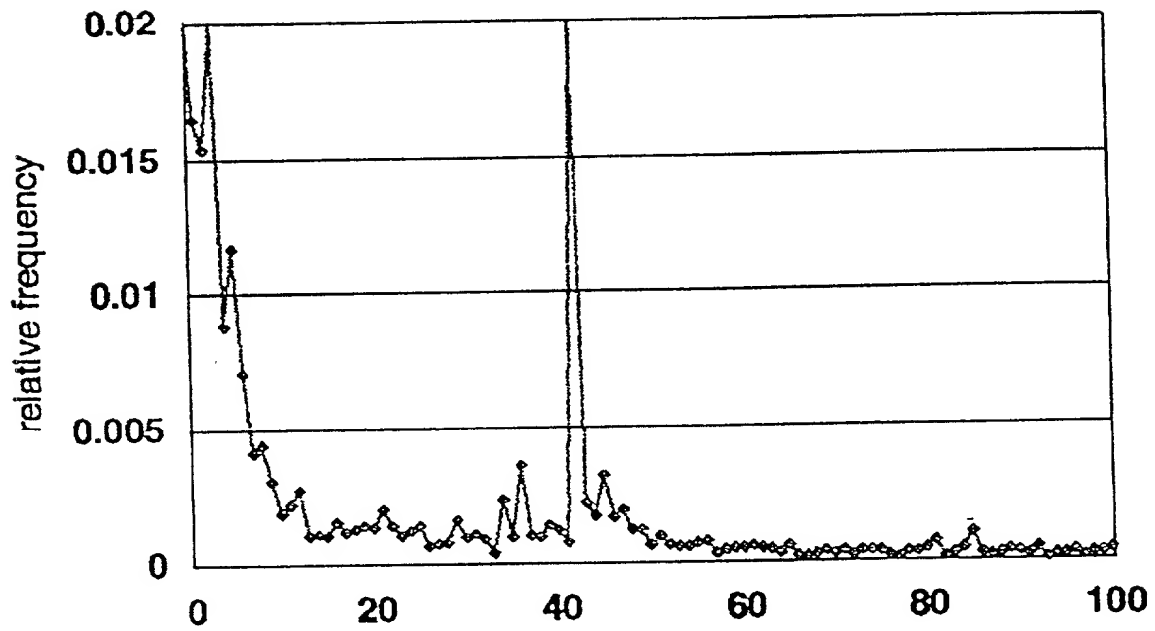


FIG. 12

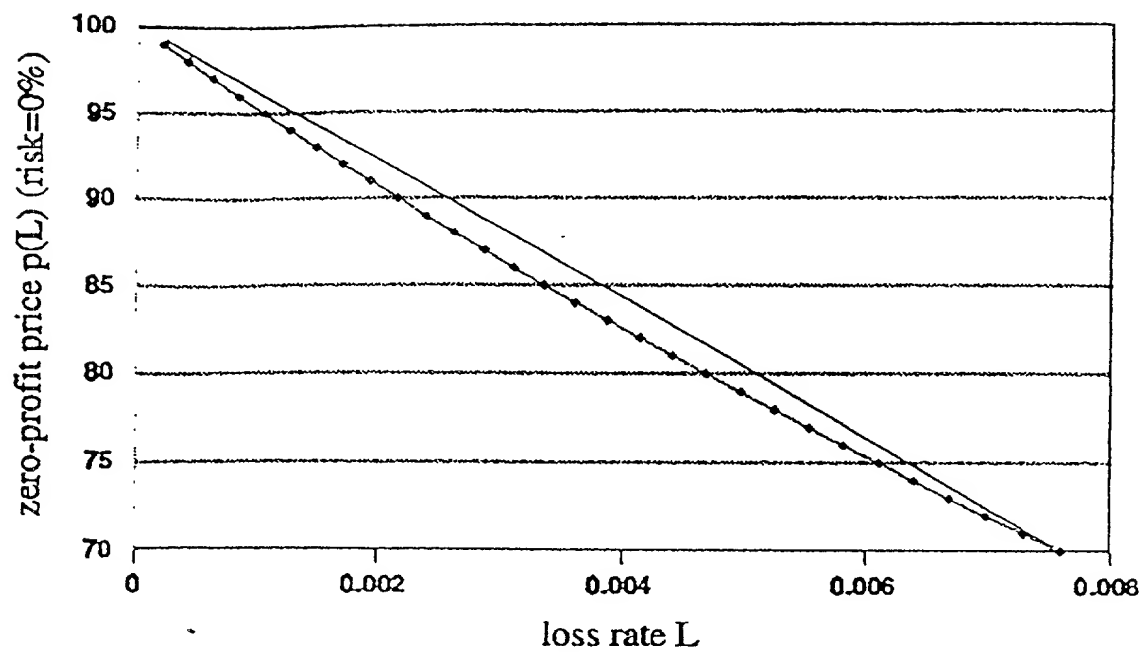


FIG. 13

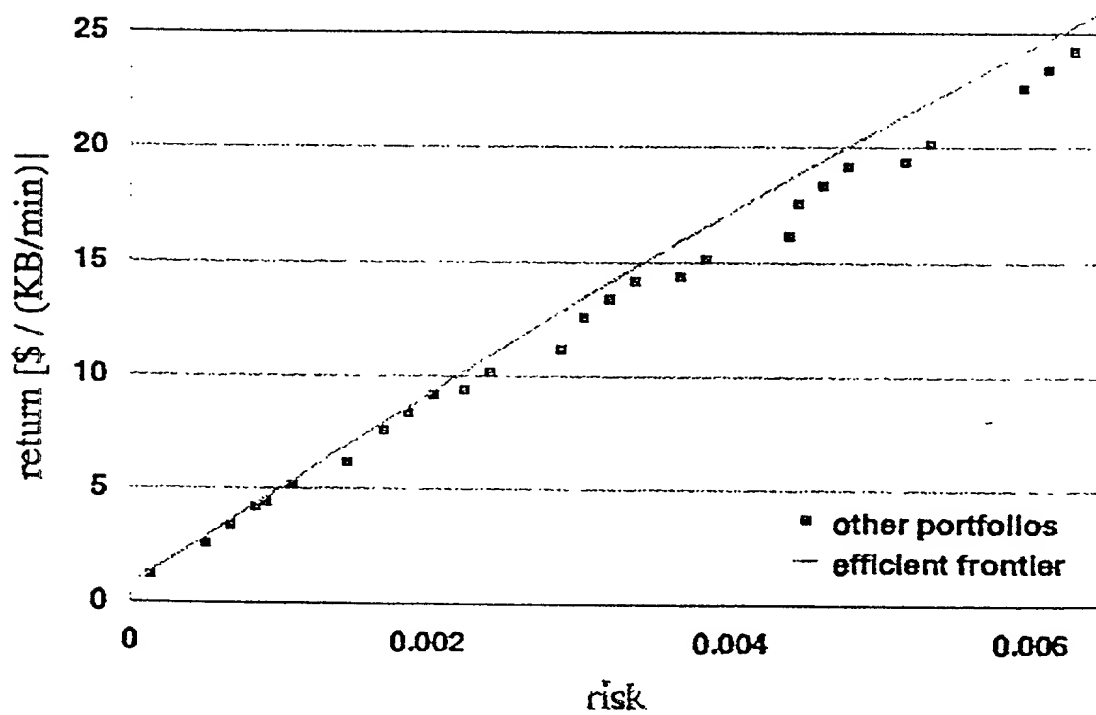


FIG. 14

**DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION**Express Mail Label EL549238338US  
Date of Deposit October 27, 2000

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

PORTFOLIO THEORY METHOD OF MANAGING OPERATIONAL RISK WITH RESPECT TO NETWORK SERVICE-LEVEL AGREEMENTS

the specification of which (check one)

X is attached hereto.

\_\_\_\_\_ was filed on \_\_\_\_\_ as United States Application Number

or PCT International Application Number \_\_\_\_\_

and was amended on \_\_\_\_\_ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, '119(a)-(d) or '365(b) of any foreign application(s) for patent or inventor's certificate, or '365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application, having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes <input type="checkbox"/> No
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes <input type="checkbox"/> No
(Number)	(Country)	(Day/Month/Year Filed)	<input type="checkbox"/> Yes <input type="checkbox"/> No

I hereby claim the benefit under 35 U.S.C. '119(e) of any United States provisional application(s) listed below.

60/162,383	October 28, 1999
(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

I hereby claim the benefit under 35 U.S.C. '120 of any United States Application(s), or '365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States, or PCT International application in the manner provided by the first paragraph of 35 U.S.C. '112, I acknowledge the duty to disclose information material to the patentability of this application as defined in 37 CFR '1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (list name and registration number).

Manny W. Schecter (Reg. 31,722), Lauren C. Bruzzzone (Reg. 35,082), Christopher A. Hughes (Reg. 26,914), Edward A. Pennington (Reg. 32,588), John E. Hoel (Reg. 26,279), Joseph C. Redmond, Jr. (Reg. 18,753), Richard M. Ludwin (Reg. 33,010), Marc A. Ehrlich (Reg. 39,966), Douglas W. Cameron (Reg. 31,596), Louis P. Herzberg (Reg. 41,500), Marian Underweiser (Reg. 46,134), Stephen C. Kaufman (Reg. 29,551), Daniel P. Morris (Reg. 32,053), Louis J. Percello (Reg. 33,206), David M. Shofi (Reg. 39,835), Robert M. Trepp (Reg. 25,933), Paul J. Otterstedt (Reg. 37,411) and Wayne L. Ellenbogen (Reg. 43,602).

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Full name of sole or first inventor

Inventor's Signature

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## DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

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Date of Deposit October 27, 2000Beat Liver

Full name of second joint-inventor, if any

Inventor's signature

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Inventor's signature

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Citizenship

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Inventor's Signature

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Citizenship

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Inventor's Signature

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Residence

Citizenship

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Full name of sixth joint-inventor, if any

Inventor's signature

Date

Residence

Citizenship

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Post Office Address